OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

15831

Paper to be presented at the UNIDO meeting on the utilization of marine algae for the benefit of people of developing countries

Riga, USSR, 5 - 8 August 1986

Utilization of marine algae as a raw material for industry, in particular for medical and pharmaceutical industries

Ulrich Horstmann
Institut für Meereskunde an der Universität Kiel
2300 Kiel, Düsternbrooker Weg 20

A presentation on the utilization of marine algae as raw material for industry and particularly for medical and pharmaceutical purposes demands a multivolume elaboration, if all species and all applications will be considered. Most of the single cell algae and almost all multicellular benthic algae contain to some extent substances of certain potentials in industry. The spectrum of substances from algae is rather diverse and includes agar and carrageenans, alginic acids and alginates as well as inorganic substances like iodine and bromine, but also compounds like alcaloids, amines, enzymes, sterols or vitamines and aminoacids. The range of application for substances from algae is rather large, and includes not only pharmaca products, but also additives in food technology, cosmetic industry or fields like leather paper and textile production.

The amount of literature on the use of algae in industry and specifically for pharmaceuticals is rather large, and there exist a number of useful review articles, some of them are published in a Volume: Marine Algae in Pharmaceutical Sciences edited by Hoppe, Levring and Tanaka, Walter de Gruyter, Berlin, New York. Further articles were presented at the 13th Seaweed Symposium in China (1984).

This presentation aims towards the specific task of the UNIDO Expert-meeting on an utilization of marine algae in third world nations.

After a short historical introduction the first chapters give some background information on the different groups of marine algae and their products in industry with emphasis on pharmaceutical products. It i furthermore tried to elaborate applications that could possibly be of use for developing countries.

HISTORICAL BACKGROUND

The first records of the utilization of algae for medicinical purposes originate from China 2700 B.C. Several species are listed in early Chinese materia medica (Shen Nung Ben Cao Jing 200 B.C. and Ben Cao Gang Mu 1581-1593). Since then algae as pharmaceuticals appear frequently in literature. for a review see Schwimmer (1955). Especially in East Asia seaweeds have been well known in folk medicine to prevent and cure all kinds of human deseases (Zaneveld 1959), as for instance goitre, nephritic deseases, anthelminthic or stomach problems and cartharrs.

In the 17th and 18th century benthic algae were used to produce potask and soda. Phycocolloids were first produced in Japan and only since the beginning of this century other countries became interested in the phyco-colloid production. The extensive seaweed industry for agar, carrageenas and other alginates is less than 70 years old. The development was rather fast, though during the last 20 years different branches in the algae industry experienced ups and downs.

RECENT DEVELOPMENTS IN THE ALGA INDUSTRY

The recent developments and aims of algae industry can be demonstrated through the initiatons of a Swiss pharmaceutical company in Australia (Roche Research Institute of Marine Pharmacology, RRIMP). When biologists, chemists, biochemists, pharmacologists and microbiologists were gathered in Australia, a country with one of the largest coastlines covering tropical and temperate waters, for the search of drugs from the sea.

The investigation which lasted 6 years resulted in a detailed catalogue of pharmacological and microbiological activities of extracts of Australian seaweeds (Baker 1984, Reichelt and Borowitzka 1984). Fig. 1. demonstrates the tidious but impressive way in modern natural-product drug research.

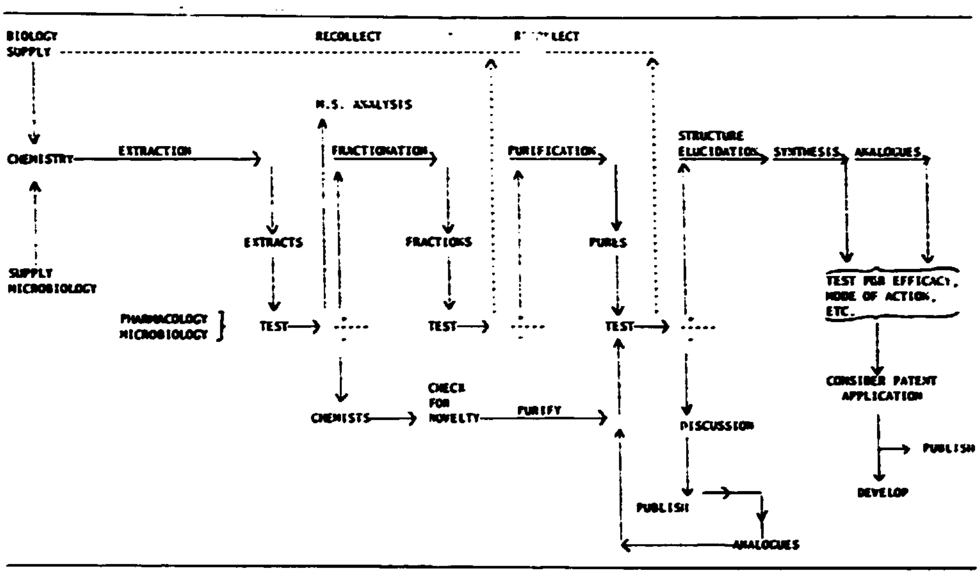

Fig. 1: Screening philosophy for marine natural product research. After Baker (1984)

Activities like those of RRIMP and other research institutions have recently led to a series of new algae obtained compounds in medicine.

A few investigations which are characteristic for the present development in the extraction of biological active compounds should be mentioned here, as for instance the detection of stypoldione and ortho-quione, a monoalcohol which is derived from the brown seaweed Stypopodium zonale which was found as part of a study by Gerwick and Fenical (1981) and which was verified to have an antitumor activity (O'Brian et al 1984).

Another recent investigation by a japanese working group deals with antitumor activities of edible marine brown algae and demonstrates the effect of crude fucoidan fractions from brown seaweeds against L-1210 leucemia.

Recent studies on biologically active compounds of the algae from the yellow sea by Niang and Hung (1984) should also be mentioned as an excellent example for the extraction of substances of antiinflammatory activities, in this case bromophenol diterpenes and dictyriol A and B from Dictyota indica.

There are other investigations pointing towards current research like those of Kaneda and Abe (1984) which attend to document the physiological value of seaweed on biochemical criteria associated with atherosclerosis and coronary heart desease.

The various bluegreen algae species should also be mentioned that contain compounds with nitrogen in the amide or indole constellations, many of those appear to be products of acetate biosynthesis. These metabolites have shown to have various bioactivities from antibacterial and antifungal to anticancer activity (Mynderse et al 1977).

It has been discovered that many red algae species contain compounds produced by acetate polymerisation. The main halogen involved in this synthesis is bromine (Fenical and Paul 1984). Many of the halogenated metabolites have shown antimicrobial activities as well as phytotoxicities and other pharmacological effects.

In contrast to the red seaweeds the brown algae do not produce halogenated metabolites, however, particularly the Dictyotoceae, the Sargassaceae and Cystoseriaceae are known to produce complex diterpenoids and metabolites of terpenoid-aromatic origins (Fenical and Paul 1984). Many of these compounds have been shown to possess various types of biological activities and there are currently various investigations for applications as antibiotics and other drugs.

Reviews of many aspects of biologically active extracts from algae can be found in the various volumes of the treatize entitled 'Marine Natural Products' edited by Scheuer (1978-81).

In general one can state that over the last decade chemical investigations of marine algae have illustrated that these plants produce a wide variety of structurally unique and biologically active secondary metabolites.

PHYCOCOLLOIDS FOR INDUSTRY AND PHARMACY

The most important industrial products from marine algae are the phycocolloids, the polysaccharide complexes of the Rhodophyta and Phaeophyta. Aside from its use, in connection with pharmaceutical products predominantly, because its colloid-chemical behaviour phycocolloids are in general important auxiliaries in numerous industries as stabilizers, gelling and emulsifying agents and as thickeners.

AGAR AND CARRAGEENAN

Agar and Carrageenan are the most important polysaccharides of the red algae. Hoppe (1979) gives a detailed list of the most common Rhodophyta used for the production of agar and carrageenan, including some information on the occurrence of algae and the phycocolloid content.

Agar is an economically important product prepared from several species of red algae, the so-called 'agarophytes'.

The most common genera used for agar production are numerous Gelidium species, Gelidiella and Gracilaria as well as Pterocladia and Acanthopeltis. The most important countries of production are: Portugal, Spain, Marocco, Japan, India, USSR, USA and Chile.

The best known use of agar is in the production of substratum for bacteriological plates. The largest amounts, however, are used in the food technology. Further applications are in pharmacy as a binding for tablets, as a laxative or an anticoagulant for blood. Agar has also applications in dentistry. Agar varies much in chemical and physical properties depending on the raw material. Agar is the oldest and perhaps the best known product of marine algae.

Algae products of increasing importance in the last 20 years are the carageenates and their deriviates.

Carrageenans are frequently used in the pharmaceutical industries as emulsifiers as well as granulation and binding agents for example in tablets. Carrageenans are used as drugs in gestric ulcer therapy and as antithrombotic agent. Carrageenans are also used in cosmetic industry as a stabilizer suspending and thickening agent in cream lotions, toothpastes, sun protection oils as well as foam stabilizers.

Five forms of carrageenans are known: Kappa, lambda, my, ypsilon and jota-carrageenan, which differ in the levels of sulfation and in the ratio of galactose to 3,6-anhydrolactose causing different physical properties. Some algae species contain specific carrageenans, others contain mixtures. In the 19th century carrageenan was mainly produced from Chondrus crispus commonly called 'Irish Moss'. In the last 70 years a number of additional species is used as raw materials for carrageenan production. In the last 20 years the mass cultivation of Eucheuma in South East Asia is of high relevance for the carrageenan industry.

-7-

The most important genera for carrageenan production are: Chondrus, Gigartina, Gelidium, Hypnea, Eucheuma, Chondrococcus, Halymenia, Laurencia, Furcellaria, Sarconema, Endocladia, Gymnogongrus, Rhodoglossum, Rhissoella and Yatabella. A detailed list of red algae used for carrageenan production can be found in Hoppe (1979).

The carrageenan industry in South East Asia is described in the second part of this presentation.

There are various other products which are obtained from red algae. Most of them have similiar properties as agar, respectively carrageenan, and are obtained from specific species, as for instance Funoran, which is also a sulphated polysaccharide and used in the cosmetic industry, but also in pharmaceutical industry where it is proposed as a blood anticoagulant drug.

ALGINIC ACID AND ALGINATES

The most important products of the Phaeophyta are alginic, acid and alginates. Major source of raw materials are Laminaria and Macrocystis species.

Especially Laminaria hyperborea plays an important role in Alginic Acid production, Levring (1978), Larsson and Hong (1961) and Sheppard et al. (1978) give detailed information on this brown algae and the commercial production of alginic acid from it.

The content of alginic acid can be subject of enormous fluctuations within the different seasons (Hoppe 1979), but also within different parts of the plant. It can range between 5 and 40 % of the dry weight.

Of great importance for the alginic acid and alginate industry is the 'Giant Kelp' Macrocystis. Extensive fields can be found along the Southern Californian coasts and the waters of north western Mexico, but the algae occur also along the coasts of South America (Peru, Chile, Argentinia) as well as Australia and New Zealand. Macrocystis porifera contains 14-21 % alginic acid (Hoppe 1979).

Further species of brown algae of importance for alginate production are: Alaria, Cystoseira, Darvillea, Ecklonia, Lessonia, Egregia, Nereocystis, Pelagophycus, Sargassum and Ascophyllum.

Several species of brown algae have not yet been sufficiantly investigated for its potential use as raw material for the alginate industry.

For further literature see Hoppe (1979).

There are many publications on the structure and biosynthesis of algenic acid as for instance Humm (1951), McNeely (1959) or Parcival and McDowell (1967). Algenic acid is not a single compound, but a complex of polysaccharides with a varying composition of guluronic and manuronic acid (Hong and Larsen 1964).

The utilization of alginates covers a large field and is continuously increasing. In the pharmaceutical industry they are used as emulsifiers, as suspension agents or stabilizers. Alginates are used as fillers in the production of pills and tablets and as vehicles and desintegrating agents. In tablets it is also used as swelling agent, because of its very high swelling strength. Ointments are made with alginates and it is used for the production of wound and blood stopping plaster. Calcium alginate is used for producing capsules, pellets and granulates.

Alginates play also an important role in the cosmetic, soup and detergent industry, one reason is its different viscosity. The ability of alginates to form films on the skin is used for an auxiliary in ointments and creams. But alginates are also used in dentistry.

Recent investigations show the future use of algenic acid to suppress the absorption of radioactive strontium.

Similar to carrageenan alginates are also used in food technology.

FURTHER SUBSTANCES FROM ALGAE FOR PHARMACY

There are numerous other constituents in algae aside from the polysaccharides which have attracted increasing interest in pharmacy.

Recent investigations by Güven et al. (1969) have shown that alcaloids can be extracted from algae.

AMINES

The occurrence of amines such as methylamine, isoamylanine or isobutylamine as well as ethylamine and propylamine have been demonstrated in green, brown and red algae (Bhakuni and Silva (1974).

Other amines have been found in micro algae by Kneifel (1979), who summarizes in his monograph the possible pharmacological use of amines from algae.

Cellulose (also called algulose) as a residue from the production of phycocolloids is also used in industry.

There are also substances like enzymes (McElvani et al. 1979), floridean starch, glycosides which are up to now insufficiently investigated as to its exploitation for industry.

The production of alcohol, aceton and organic acids from marine brown algae has been tested, also in UDSSR (Fott 1971) but seems not to be of great economical value.

INORGANIC SUBSTANCES FROM ALGAE

There are several inorganic substances in algae which are of present and potential importance for industry. The production of iodine and iodine salts from algae plays a considerable role in pharmaca production. In general brown algae are used for the production of iodine. However, there is one redalga species (Phyllophora) which is used for iodine extraction in USSR.

Bromine is obtained from redalgae. Especially species of Rhodomela Odonthalia and Polysiphonia are required for bromine production.

The production of potassium salts from seaweeds has decreased and is nor more of value.

A comprehensive survey of inorganic components of marine algae was given by Vinogradow (1953).

There are numerous trace elements accumulated in seaweeds and even more important also for the use of algae as fertilizers is the content of mineral nutrients, as there is nitrogen, phosphorus, potassium, calcium and magnesium.

SPECIAL ALGAL CONSTITUENTS

There are further substances like lipids (Lit Nogudi et al. 19?9), sterols, steroids as well as fatty acids (Pohl and Zurheide 1979) and phenolic compounds found in algae who might be of importance in the future in algae industry.

Phytohormones like auxins and gibberellins are found in algae. Plant growth regulatory substances in algae have been intensively investigated by Angier (1978). It is also reported that phytohormones play a role in the development of certain remedies and cosmetics (Schmidt 197i).

-11-

CAROTENE FROM ALGAE

The extraction of pigments from algae seems to be a realistic near-future venture in algae industry. From the 4 groups of pigments which are found in algae: the chlorophylls, carotenese, xanthophylls and phycobilins, the carotenese are of main importance for industry.

Background information on carotenoids in algae can be obtained from Wettern and Weber (1979). At present the extraction of Carotenoids from seaweeds seems not to be economical. However, the mass cultivation of the greenalga Dunaliella aims towards the industrial production of carotin. We will report on this later in this presentation.

SOME MEDICAL AND NUTRITIONAL ASPECTS

As further substances of industrial potentials the proteins should be mentioned, however, they are important for the use of algae as food.

For nutrition but also for medical purposes the potentials of amino acids extraction from seaweeds is important (Takagi 1970, Hoppe 1975). Laminine, Gigartine and Gongrine are aminoacids from algae which have medical effects.

Constituents of marine algae like vitamines, amino acids and trace elements which can be found in quite high concentrations in algae are important, because of the indirect medicinical effects as preventive remedies. An application which especially in third world nations could be of future value. Müller Plettenberg (1977) writes about the indirect medicinical effects of substances of marine algae: 'The characteristic of many old remedies with small acute toxicity consists of bringing about a change of the morbide disturbance of metabolism pretty much as would hormones and vitamines. Thus they not only remove symptoms, but become real remedies.'

Table 1 shows a list of macroscopic marine green, brown and red algae of commcercial use (after Bonotto, based on papers published by various authors)
Predominantly used in industry: iu, for medical purposes: ma, as Human food: hf, animal food: mf, manure: ma; en: possible energy source

Green Algae.

Codium sp.	hf, mp
C. dichotomum	hf
C. divaricatum	hf
C. fragile	hf
C. intricatum	hf
C. lindenbergii	hf
C. muelleri	hf
C. tenue	hf
C. tomentosum	hf, iu
Enteromorpha compressa	hf, af
E. flexuosa	hf
E. intestinalis	hf, af
E. linza	hf, af
E. prolifera	hf
Monostroma crassissimum	hf, af
M. grevillei	hf, af
M. latissimum	hf, af
M. nitidum	hf, af
M. tubuliforme	hf, af
Prasiola japonica	hf
Ulva fasciata	hf
U. lactuca	hf, af, mp, ma
U. latissima	hf, af
U. nematoida	hf
U. penniformis	mp
U. pertusa	hf, af, mp
U. reticulata	mp

Brown Algae

Agarum cribrosum	iu
A. fimbriatum	iu
Alaria esculenta	hf, af, ma
A. fistulosa	hf
A. marginata	ma
A. ochotensis	hf
A. yezoensis	hf
Arthrotamnus bifidus	hf
A. kurilensis	hf
Ascophyllum nodosum	af, ma, iu
Chnoospora pacifica	hf
Chorda filum	hf
Chordaria flagelliformis	hf, mp
Costaria costata	hf
Cystophora sp.	af
Cystophyllum sp.	hf
Dictyopteris polypodioides	hf, mp
(Syn : *D. membranacea*)	
D. plagiogramma	hf
Dictyota acutiloba	hf
D. apiculata	hf
Durvillea antarctica	hf, af, mp, ma, iu
Ecklonia bicyclis	iu
E. cava	iu
E. kurome	hf
E. latifolia	hf
E. maxima	af, ma, iu
Eckloniopsis sp.	hf, iu
Egregia menziesii	ma, iu
Eisenia bicyclis	hf, ma, iu
Endarachne sp.	hf
Fucus serratus	af, ma, iu
F. vesiculosus	af, mp, ma, iu
Heterochordaria abietina	hf
Himanthalia elongata	ma, iu
(Syn: *H. lorea*)	
Kizikia fusiforme	hf
Hormosira banksii	af
Hydroclathrus clathratus	hf, ma
(Syn: *H. cancellatus*)	
Kjellmaniella gyrata	hf
(Syn: *Laminaria gyrata*)	
Laminaria angustata	hf, iu
L. cichorioides	hf
L. diabolica	hf, iu
L. digitata	af, ma, iu
L. fragilis	iu
L. hyperborea	af, ma, iu
(Syn: *L. cloustonii*)	
L. japonica	hf, mp, iu
L. longipedalis	hf
L. longissima	hf, iu
L. religiosa	hf
L. saccharina	af, ma, iu
Lessonia sp.	iu
L. variegata	ma
Macrocystis integrifolia	af, ma, iu
M. pyrifera	af, ma, iu, en
Mesogloia crassa	hf
M. decipiens	hf
Nemacystis decipiens	hf
Nereocystis luetkeana	hf, af, ma, iu
Padina australis	af, ma
Pelagophycus porra	ma, iu
Pelvetia canaliculata	af, ma
Petalonia fascia	hf
(Syn: *Phyllitis fascia*	
Ilea fascia)	
Sargassum aquifolium	hf
S. echinocarpum	hf
S. enerve	hf, iu
S. fusiforme	hf, mp, ma, iu
S. granuliferum	hf
S. hemiphyllum	ma
S. horneri	iu
S. linifolium	iu
S. micracanthum	iu
S. natans	mp
(Syn: *S. bacciferum*)	
S. nigrifolium	iu
S. polycystum	hf
S. serratifolium	hf, iu
S. siliquosum	hf
S. sp.	hf, af, ma
S. tenerrimum	ma
S. thunbergii	af, mp, ma
S. vulgare	hf
S. wrightii	ma
Scytosiphon sp.	hf
Spiachnidium rugosum	hf
Tinocladia sp.	hf
Turbinaria sp.	ma
T. ornata	hf
Undaria peterseniana	hf
U. pinnatifida	hf, mp
U. undarioides	hf

Red Algae

Acanthopeltis japonica	hf, iu
Acanthophora spicifera	hf
[illegible]	iu
Agardhiella tenera	iu
Ahnfeltia concinna	hf, iu
A. plicata	iu
Alsidium helminthochorton	mp
Asparagopsis sanfordiana	hf
Beckerella sp.	iu
Bostrychia radicans	hf
Caloglossa adnata	hf
C. leprieurii	hf
Campylaephora crassa	iu
C. hypnaeoides	hf
(Syn: *Ceramium hypnaeoides*)	
Carpopeltis affinis	iu
C. flabellata	iu
Catenella impudica	hf
C. nipae	hf
Ceramium aduncum	iu
C. boydenii	iu
C. cimbricatum	iu
C. cliatum	iu
C. codii	iu
C. crassum	iu
C. fastigiatum	iu
C. fimbriatum	iu
C. gracillimum	iu
C. kondoi	iu
C. nakamurai	iu
C. paniculatum	iu
C. rubrum	iu
C. tenerrimum	iu
C. tenuissimum	iu
Chondria armata	mp
Chondrus crispus	hf, af, mp, iu
C. elatus	hf
C. ocellatus	iu
C. pinnulatus	iu
C. platinus	hf
C. yendoi	iu
Corallina officinalis	mp
Cryptonemia decumbens	hf
Cystoclonium armatum	hf
Digenea simplex	hf, mp
Dilsea edulis	hf
Dumontia incrassata	hf, iu
Eucheuma amakusaensis	iu
E. cottonii	iu
E. crustaeforme	iu
E. cupressoideum	hf, iu
E. edule	hf
E. gelatinae	hf, iu
(Syn: *E. gelatinosa*)	
E. horridum	hf, iu
(Syn: *Gigartina horrida*)	
E. isiforme	iu
E. muricatum	hf, iu, mp
(Syn: *E. spinosum*, *E. denticulatum*, *Fucus muricatum*)	
E. okamurai	hf, iu
E. serra	hf, iu
E. striatum	hf, iu
Furcellaria fastigiata	iu
Gelidiella acerosa	hf, iu
(Syn: *Gelidium rigidum*)	
Gelidiopsis rigida	hf, iu
Gelidium amansii	iu
G. arborescens	iu
G. arbuscula	iu
G. attenuatum	hf
G. capillaceum	iu
G. cartilagineum	iu
G. corneum	iu
G. crinale	iu
G. decumbensum	iu
G. divaricatum	iu
G. elegans	iu
G. incurvatum	iu
G. japonicum	iu
G. johnstonii	iu
G. kintaroi	iu
G. latifolium	hf
G. liatulum	iu
G. lingulatum	iu
G. linoides	iu
G. micropterum	iu
G. nudifrons	hf, iu
G. pacificum	hf, iu
G. planiusculum	iu
G. polycladum	iu
G. polysticum	iu
G. pristoides	iu
G. pulchellum	iu
G. pulchrum	iu
G. pulvinatum	iu
G. purpurascens	iu
G. pusillum	iu
G. pyramidale	iu
G. rigens	hf
G. sp.	hf, mp, iu
G. subcostatum	hf
G. subfastigiatum	iu
G. tenue	iu
G. vagum	iu
Gigartina chamissoi	iu
G. exasperata	iu
G. clavifera	iu
G. decipiens	iu
G. intermedia	iu
G. ookotensis	iu
G. pacifica	iu
G. pistillata	hf, iu
G. stellata	iu
(Syn: *G. mamillosa*)	
G. teedii	iu
G. tenella	iu
Gloiopeltis complanata	iu
G. furcata	iu
G. tenax	iu
Gracilaria arcuata	iu
G. blodgettii	iu
G. bursa-pastoris	iu
G. caudata	iu
G. chorda	iu

G. compressa	hf, iu
G. confervoides	hf, ma, iu
G. cornea	hf
G. coronopifolia	hf, iu
G. crassa	iu
G. denticulata	iu
G. dura	iu
G. edulis	hf, iu
G. eucheumoides	hf
G. gigas	iu
G. incurvata	iu
G. multipartita	iu
(Syn: *G. lacinulata*,	
G. foliifera)	
G. punctata	iu
G purpurascens	iu
G. salicornia	iu
G. sublittoralis	iu
G. taenioides	hf, iu
G. textorii	iu
G. verrucosa	iu
Gracilariopsis chorda	iu
G. rhodotricha	iu
G. vermiculophylla	iu
Grateloupia divaricata	hf, iu
G. filicina	hf, iu
G. imbricata	hf, iu
G. okamurai	hf, iu
Gymnogongrus flabelliformis	hf, iu
G. griffithsiae	iu
G. javanicus	hf
G. pinnulata	hf, iu
Halosaccion glandiforme	hf
Halymenia durvilliae	hf
Hypnea boergesenii	iu
H. cenomyce	hf, iu
H. cervicornis	hf, iu
H. charoides	iu
H. chordacea	iu
H. cornuta	iu
H. divaricata	hf
H. esperi	iu
H. flabelliformis	iu
H. hamulosa	iu
H. japonica	iu
H. musciformis	iu
H. nidifica	hf, af, mp
H. nidulans	iu
H. pannosa	iu
H. saidana	iu
H. spicifera	iu
H. valentiae	iu
H. variabilis	iu
Iridaea cornucopiae	iu
I. edulis	hf
I. flaccida	iu
(Syn: *I. laminarioides*)	
Laurencia botryoides	hf
L. obtusa	hf
L. papillosa	hf
L. perforata	hf
L. pinnatifida	hf
Liagora farinosa	hf
L. decussata	hf

Lithothamnion calcareum	ma
L. crassum	ma
Mastocarpus klenzianus	hf
Meristotheca papulosa	hf, iu
Nemalion multifidum	hf
Neodilsea yendoana	iu
Odonthalia corymbifera	iu
Pachymenia himantophora	ma
Pachymenia sp.	iu
Pachymeniopsis elliptica	hf, iu
Phyllophora brodiaei	iu
P. membranifolia	iu
P. nervosa	iu
P. rubens	iu
Plumaria plumosa	ma
Porphyra angusta	hf
P. atropurpurea	hf, mp
P. columbina	hf
P. dentata	hf
P. kuniedai	hf
P. kunthiana	hf
P. laciniata	hf
P. leucosticta	hf
P. nereocystis	hf
P. ochotensis	hf
P. okamurai	hf
P. onoi	hf
P. perforata	hf
P. pseudo-linearis	hf
P. purpurea	hf
(Syn: *P. umbilicalis*	
f. laciniata)	
P. suborbiculata	hf
P. tenera	hf
P. umbilicalis	hf
P. vulgaris	hf
P. yezoensis	hf
Pterocladia capillacea	iu
(Syn: *P. pinnata*)	
P. densa	iu
P. lucida	hf
P. nana	iu
P. tenuis	iu
Rhodoglossum hemisphaericum	iu
R. japonicum	iu
Rhodymenia indica	mp
R. palmata	hf, af, mp
Sarcodia montagneana	hf
Soliera chordalis	ma
Sphaerococcus cartilagineus	mp
Suhria vittata	hf, iu
Turnerella mertensiana	iu

APPLICATIONS FOR THIRD WORLD NATIONS

From this short overview on marine algae and their products one can conclude that there are different ways of utilizing algae. On the one side is the raw product of wet or dried algae, on the other are extracts after sophisticated steps of purification. There are several intermediate products which need more or less emphasis in processing.

For third world nations the more complicated extraction procedures can rarely be realized and will be excluded from this discussion, which, however, reduces the number of products derived from algae drastically and leads more or less to the production of raw material for direct use or for export.

The prerequisite for benthic algae growth is a shoreline with a hard bottom substratum. In the tropical region - and this is where most of the third world nations are found - near surface coral reefs and coraline tidal flats give an excellent substratum for algal growth.

NONE EXPLOITED RESOURCES

The resources of benthic algae in tropical regions are not at all fully exploited. Levring (1978) states that the seaweed resources of the world are only to a fairly low extent exploited. According to Levering (1978) the global production of red algae could be increased by 50 % and the biomass of the brown algae would probably allow an increase of utilization by twenty times.

EDUCATIONAL WORK, AND IMPROVEMENT OF INFRASTRUCTURE

The possibility of increasing harvesting depends to a great extent on economic factors, the demand of products, and the cost of harvesting. Aside from economic factors, however, in many regions of third world nations educational work as to the species of economical value, harvesting and processing would be of considerable success.

Travelling in southeast Asia I have repeatedly observed tremendous natural stocks of red algae of high value for the carrageenan industry, of which nobody ever took notice. On Mindoro Island for instance large amounts of Gracilaria could be found to have accumulated due to tidal currents at certain areas along the beach. The native population, however, considered the desintegrating algae as trouble some garbage.

Aside from education, I have repeatedly observed that missing infrastructure does not permit an adequate marketing of seaweeds in developing countries.

CONTROLLED HARVESTING AND MASSCULTIVATION

A second step for increasing the seaweed production in third world nations is the controlled harvesting. Again in southeast Asia it can be observed that seaweeds in certain areas after harvesting are almost eradicated and no seedlings are left for propagation.

Controlled harvesting includes also the removal of predators like certain Molluscs and Echinodermata. Here again educational work could achieve a considerable increase of production.

The mass cultivation of seaweeds can be considered as a third step to increase the production raw material in developing countries. This topic exceeds the frame of this presentation. However, since the production and use of seaweeds are jointly connected I will shortly report on some experiences from the Eucheuma cultivation for phycocolloids in the Philippines.

SOME ASPECTS OF THE RED ALGA INDUSTRY IN THE PHILIPPINES

Since long different species of Eucheuma have been considered as an item of food in various countries in the Pacific region. Only in the middle of this century Eucheuma was discovered as an excellent source for the carrageenan production (Doty 1977). This caused especially in the Philippines an overexploitation of Eucheuma, which led almost to an irradication of this seaweed.

Its cultivation was almost incidentically - a fisherman who had collected seaweeds had left some algae which he could not sell in a net container under water and realized that the algae continued to grow -. This was the beginning of the Eucheuma cultivation in the south Philippines in the early 1950ies. The next 20 years, mainly due to the emphais of the few companies who bought the dried raw material for carrageenan extraction the seaweed cultivation increased to a rather important economical factor for the rural population and especially for those families in South East Asia that suffered from overfishing. Due to the fact that only a few companies in France, USA and Denmark were capable of high quantity and quality carrageenan extraction the price of raw material depended rather on these companies which led to extraordinary fluctuations in the price of dried Eucheuma in the 1970ies. As a consequence the economical situation of seaweed farming families in the Philippines, for which seaweed farming is more or less a question of survival suffered a lot.
For my experience at that time limited technical know how would have been needed to set up a carrageenan extraction plant in the Philippines. This would have saved a high amount of shipping costs - the weight and volume of carrageenan powder is only a small percentage of that of dried saltcovered seaweeds -, in addition there definitely would have been a more reasonable and stable pricecost-relation.

Today the Eucheuma industry is still an expanding venture also in China (Wen-Young 1984, Sigian and Ping 1984) and along the coast of east Africa from where Mahigeni K.E (1984) reports of Eucheuma being an underexploited resource.

TRANSFER OF PROCESSING PLANTS INTO PRODUCTION AREAS

For a number of raw algal raw products produced in third world nations quite simple processing technologies are required and if transferred to the areas of seaweed production can help to establish a healthy algae industry in developing countries. However, one should be aware that the recent developments in pharmaca from seaweeds mostly aim towards sophisticated extraction or processes which almost always underlies the rules and laws of protection by patent. In these cases developing countries can only profit from the export of raw material or semi-processed products.

UTILIZATION OF KNOW HOW OF FOLK MEDICINE

Algae in medicine and pharmacology do not always require complicated processing. Tseng and Chang (1984) report about Chinese seaweeds in herbal medicine which are active previous to any treatment (see Table 2). Misra and Sinha (1979) in an article on algae as drug plants in India enumerate several algae species which are for centuries experiented to be active against various health hazards. In many cases there is sufficient scientific proof for the effect of compounds involved. In other cases psychosomatic treatment might also be involved.

Fig 2: Distribution of endemic goitre and of seaweed resources.

Areas where endemic goitre has been found (after Kelly and Snedden 1960)
Areas rich in resources of brown algae
Areas rich in red algae

After Michanek 1979.

Table 2 Utilization of Chines seaweeds in herbal medicine and folk-medicine on the bases of old Chinese literature

1. Vermifuges.
   Grateloupia livida
   Caloglossa leprieurii
   Digenea simplex
   Codium fragile
2. Treatment of goiter and scrofula.
   Porphyra haitanensis
   Porphyra spp.
   Gloiopeltis furcata
   G. tenax
   Gracilaria verrucosa
   G. eucheumoides
   Eucheuma gelatinae
   Nemacystus decipiens
   Laminaria japonica
   Ecklonia kurome
   Sargassum fusiforme
   S. hemiphyllum
   S. henslowianum
   S. horneri
   S. pallidum
   S. polycystum
   S. siliquastrum
   S. vachellianum
   Enteromorpha spp.
3. Antipyretics and coolers (refreshing liquid) and treatment of sunstroke.
   Sargassum fusiforme
   Sargassum spp.
   Ulva conglobata
   U. fasciata
   U. lactuca
   U. pertusa
   Enteromorpha prolifera (O.F. Müll.) J. Ag.
   Enteromorpha spp.
4. Treatment of cough, bronchitis, tonsillitis, and asthma with excessive phlegm.
   Porphyra haitanensis
   Gloiopeltis furcata
   G. tenax
   Eucheuma gelatinae
   E. muricatum
   Nemacystus decipiens
   Enteromorpha prolifera
   Enteromorpha spp.
5. Treatment of urinary diseases and dropsy.
   Porphyra haitanensis
   Gracilaria verrucosa
   Nemacystus decipiens
   Laminaria japonica
   Ecklonia kurome
   Undaria pinnatifida
   Sargassum fusiforme
   S. pallidum
   Sargassum spp.

   U. pertusa
   Codium fragile
6. Treatment of stomach ailments, hemorrhoids and anal fistulas.
   Gelidium divaricatum
   Gloiopeltis furcata
   G. tenax
   Gracilaria eucheumoides
   Eucheuma gelatinae
   E. muricatum
   Laminaria japonica
   Ecklonia kurome
   Undaria pinnatifida
7. Miscellaneous uses.
   a) as preventive medicine for hypertension – *Porphyra haitanensis*;
   b) for rheumatic arthritis and tuberculosis – *Gloiopeltis furcata, G. tenax;*
   c) as laxative and tonic for lying-in women – *Ecklonia kurome;*
   d) for boils – *Ecklonia kurome, Ulva lactuca;*
   e) for nose-bleeds and sore-hand – *Enteromorpha prolifera* and *Enteromorpha* spp.; and
   f) for leucorrhea (women) and nocturnal pollution (men) *Undaria pinnatifida.*

In our modern society natural products seem to play an increasing role in nutrition and health treatment. In this respect little attention has been paid to the plants from the oceans.

ONE EXAMPLE: IODINE AGAINST GOITRE

Travelling through the Peruvian parts of the Andes I was surprized when I saw high up in the mountains on the market of Huamanchijco a woman having a few small thalli of the marine red alga Gracillaria for sale. When I asked my accompany, a well educated young Peruvian for the use of these marine algae far away from the sea, he answered that a few old people eat these algae for some mystic reasons.

Only some years later I realized that the sale of marine algae in the Anden mountains is most probably an old traditional remedy against goitre which is very common in that area due to iodine deficiency. It seems as if younger generation have forgotten about it.

Endemic goitre is still a torment in many areas with low soil iodine (Fig. 2). Michanek's (1979) extrapolations from available statistics states a number of 300 million incidents of goitre in the world. Thyroid enlargement caused by low iodine content in food is often accompanied by physical and mental retardation. Goitre is mainly bound to inland and highland areas with limited infrastructure among poor people.

The number of goitre cases in Mexiko is about forty times higher than in USA. In eight Mexican states investigated 20 % of the population were goitrous (Michanel 1979). According to Michanek great goitre zone extends through Mexiko and Central America. There are also stretches along the Pacific coast where the disease can be found. Recent investigations in Northern Germany point towards an iodine deficiency especially during the female population of Schleswig-Holstein of 10 % of the population.

This shows that the goitre problem is not only due to distribution problems but also to food habits. Both can be changed and are strongly recommended to be considered as a project for UNIDO activities. Further background information on this topic see Michanek 1979).

MICROALGAE FOR β-CAROTINE PRODUCTION

Up to here we have mainly dealt with multicellular benthic algae and neglected the capability of microalgae for industrial use and the utilization for medical purposes. This is due to the fact that microalgae up to now have not reached any major importance in industry.

Different from all the predictions in the early 1950ies microalgae have neither found its way into food production nor any major importance as raw material in general.

Reasons for this are the high costs for microalgae mass production. Almost all microalgae projects have failed in the pilot plant stage because of the high energy costs demand for pumping, turbulence, aeration including CO_2 addition as well as for straining or centrifugation and finally for drying.

Large scale production plants do still require expenses of more than US$ 3 for one kg of dried microalgae. For food or feeding purposes the costs are still one order of magnitude higher than products of similar nutritional value like sojabeans or fishmeal.

-24-

The mass production of micro algae, however, is still undertaken and has a certain future for specific products in feed production for aquaculture organisms (Horstmann 1985), in the food industry, for cosmetics but also in the production of pharmaca (Chapman 1979, De Pauw et al. 1984).

Presently there is a limited production of the bluegreen alga Spirulina in artificial race ways in Thailand and in shallow water lakes in Mexico. The dried algal product is sold as so-called health pills of doubtful medical value. However, there seems to be a good future for specific microalgae species and specific applications.

The halophile green alga Dunaliella is one of these specific species which in the last 2 decades has been intensively investigated for the production of glycerol but mainly -carotine (Ben-Amotz and Avron 1980). Trial operations have been established in USSR (Masynk 1968), in Israel (Ben-Amotz and Avron 1980) and Australia (Borowitzka et al. 1984). β-carotin, though synthetically produced obtains a considerable price on the world market. Table 3 shows the price per kg in US$ compared to other algal products.

	Approx. US$ · kg^{-1}
Synthetic β-carotene	100-300*
Agarose (laboratory grade)	110
Nori *(Porphyra)*	29
Agar-agar	12
Carrageenan	9
Alginates	5-8
Single-cell protein	1
Seaweed meal	0.3
Hydrocarbons ($30 per barrel)	0.2

* Depends on formulation.

Table 3: 1983 prices of some existing and potential algal products (After Borowitzka et al. 1984)

In spite of the considerable high price of carotin the mass cultivation of Dunaliella could not yet been developed into an industrial stage. Investigations involved in this venture still try to optimize the growth conditions (salinity, nutrients) as well as the control of predators, competitors and pathogens and are furthermore engaged in the improvement of the harvesting and processing.

AN ALTERNATIVE TO HIGH TECHNOLOGY CAROTIN PRODUCTION

In 1980 there was the task to find alternatives to the Scenedesmus production in German microalgae mass production plants which were set up in Thailand and Peru. The microalgae were not accepted as food by the native population. As a consequence in 1981 we undertook production experiments with red strains of carotin rich Dunaliella salina in the high technology production plants situated in the coastal deserts near Trachillo in Peru as well as in Bangkok, Thailand. We experienced that the eurohaline species Dunaliella could comparatively easily be massproduced in the raceways. To save energy for centrifugation and other straining procedures for harvesting were avoided, but the Dunaliella suspension was sundried to a cristallin Dunaliella salt product of redish color and pleasant smell. It was furthermore tried in a very small experimental scale to distribute this product among the very poor population in a slum area in Lima, Peru, where the deficiency of the provitamin A today still leads to serious health damage especially with children. The project was not followed up. However, the production of Dunaliella salt for the provitamin A production in third world nations is still considered as a realistic contribution to fight a-vitaminosis, which among the poorest people today still leads to severe eyedeseases and to blindness.

CONCLUSIONS

The utilization of algae for industry has several prospects for application in third world nations. From my own experience in developing countries I have drawn the conclusion that projects which are profitable in industry mostly do not need development aid. The stimulus for profit does rarely know any infrastructure problems and seems to penetrate even into the most remote regions of the world. This is why it is proposed to utilize the algae and their products for the benefit of those very poor people who suffer from malnutrition and deseases. It even more can contribute to the economy and within the industrial development of third world nations.

As a first and important step educational work is needed as to the utilization of algae for nutrition and pharmaca.
Furthermore, controlled harvesting and mass cultivation should be introduced.
Processing technologies as long as they are not too sophisticated should be transferred to the locations of production into developing countries even if only semi-processed products can be achieved.
For medical applications it should be realized that marine algae are capable to produce the most urgent needed pharmaca and remedies for the poorest people suffering from malnutrition.

Among the possible pharmaceutical uses discovered within the last few years there is one which may change the whole pattern of seaweed, trade and industry: the tumor inhibiting substances. If finally remedies for cancer can be extracted from seaweeds new mariculture ventures and totally new industries would arise and would also affect those third world nations which can produce the seaweeds containing such drugs.

Education and adequate distribution should be considered as the most urgent demands offering realistic projects for an United Nations Organization which among others has the obligation to contribute to the right of freedom from deseases for all people in the world.

LITERATURE

Augier, H. 1978: Les Hormones des Algues. Etat Actuel de Connaissances. Botanica Marina XXI (3): 175-197

Baker, J.T. 1984: Seaweeds in Pharmaceutical Studies and Applications Hydrobiologica 116/117, 29-40.

Bhakuni, D.S. and M. Silva 1974: Biodynamic Substances from Marine Flora. Botanica Marina XVII (1): 40-51.

Ben-Amotz, A. and M. Avron 1980: Glycerol, -Carotene and Dry Algal Meal Production by Commercial Cultivation of Dunaliella. In: G. Shelef and C.J. Soeder (eds.), Algae Biomass. Elsevier North-Holland Biomedical, Amsterdam: 603-610.

Borowitzka, M.A. et al. 1984: The Mass Culture of Dunaliella salina for Fine Chemicals: From Laboratory to Pilot Plant. Proceed. 11th Int. Seaweed Symp. 115-120.

Chapman, V.I. 1979: Seaweeds in Pharmaceuticals and Medicine: A review. In Marine Algae in Pharmaceutical Science de Gruyter, Berlin, New York 139-147.

De Pauw, N. 1984: Massculture of Microalgae in Aquaculture Systems: Progress and Constraints. Hydrobiologica 116/117, 122-134.

Doty, M.S., Alvarez, V.B. 1974: The Productivity of Eucheuma Forms. In: Abstracts of the VIIIth International Seaweed Symposium, Bangor, 1974. Marine Science Laboratories, Anglesey.

Fenical, W. and Paul, V.J. 1984: Antimicrobial and Cytotoxic Terpenoids from Tropical Greenalgae of the Family Udoteaceae. Hydrobiologica 116/117, 135-140.

Fott, B. 1959, 1971: Algenkunde, Gustav Fischer Verlag, Jena.

Güven, K.C. et al. 1969: About Alcaloid Content of Marine Algae. Eczacilik Bülteni, XI, 177-184.

Haug, A., Larsen, B. 1964: Studies on the Composition and Properties of Alginates. In: Proceedings of the IVth International Seaweed Symposium Biarritz, 1961. Pergamon Press, Oxford - London - New York - Paris.

Hoppe, H.A. 1979: Marine Algae and their Products and Constituents in Pharmacy and Marine Algae in Pharmaceutical Science. Walter de Gruyter, Berlin, New York. 25-119.

Horstmann, U. 1985: The Use of Microalgae in Aquaculture. Arch. Hydrobiol. Ergebnisse Limnol. 20, 153-156.

Humm, H.J. 1951: The Red Algae of Economic Importance - Agar and Related Phycocolloids. In: Marine Products of Commerce. Tressler, D.K. and Lemon, J.Mc.W., ed., Reinhold Publishing Corporation, New York.

Kaneda, T., Ando, H. 1972: Component Lipids of Purple Laver and their Antioxygenic Activity. In: Proceedings of the VIIth International Seaweed Symposium, Sapporo, 1971. University of Tokyo Press.

Kneifel 1979: Amines in Algae. In: Marine Algae in Pharmaceutical Science. de Gruyter, Berlin - New York, 365-401.

Larsen, B., Haug, A. 1961: The Distribution of Iodine and other Constituents in Stipe of Laminaria hyperborea (Gunn.) Foslie. Botanica Marina II (3/4): 250-254.

Levring, T. 1978: Potential Yields of Marine Algae - with Special Reference to European Species. In: The Marine Plant Biomass of the Pacific Northwest Coast ed. by R.W. Krauss. Oregon State University Press, Corvallis.

McNeely, W.H. 1959: Fucoidan. In: Industrial Gums. Whistler, R.L. - J.N. Be Miller, ed. Academic Press Inc., New York.

Mshigeni, K.E. 1984: The Red Algal Genus Eucheuma in East Africa: An Underexploited Resource. Proceed. 11th Int. Seaweed Symp., 347-350.

Müller-Plettenberg, D. 1977: Bericht über den 52. Fortbildungskongreß für Naturheilverfahren, 1977. Deutsche Apotheker Zeitung 117, (31).

Niang, L.L. and X. Hang 1984: Studies on the Biologically active Compounds of the Algae from the Yellow Sea. Proceed. 11th Int. Seaweed Symp. 168-170.

Noguchi, T. et al. 1979: Lipid Constituents of the Red Algae Ceramium rutrum. A Search for Antimicrobial and Chemical Defense Substances. In: Marine Algae in Pharmaceutical Science. de Gruyter, Berlin - New York, 711-745.

O'Brian, E.T. et al. 1984: Pharmacological Properties of a Marine Natural Product, Stypoldine Obtained from the Brown Algae Stypopodium zonale. Proceed. of 11th Seaweed Symp. 141-145.

Percival, E., McDowell, R.H. 1967: Chemistry and Enzymology of Marine Algal Polysaccharides. Acad. Press Inc. Ltd., London and New York.

Pohl, P. and F. Zurheide 1979: Fatty Acids and Lipids of Marine Algae and the Control of their Biosynthesis by Environmental Factors.
In: Marine Algae in Pharmaceutical Science. de Gruyter, Berlin - New York, 473-523.

Reichelt, J.L. and M.E. Borowitzka 1984: Antimicrobial Activity from Marine Algae: Results of a Large Scale Screening Programme. Proc. Int. Seaweed Symp. 11: 158-168.

Sheppard, C.R.C. et al. 1978: Studies on the Growth of Laminaria hyperborea (Gunn.) Fosl. and Laminaria ochroleuca de la Pylaie on the French Channel Coast. Botanica Marina XXI, (2): 109-116.

Sijian, L. and Piug, Z. 1984: The Commercial Cultivation of Eucheuma in China. Proceed. 11th Int. Seaweed Symp. 243-245.

Scheuer, P.J. 1978-81: Marine Natural Products: Chemical and Biological Perspectives, 1-4 Academic Press, New York.

Schmidt, H.-W. 1971: Die Phytohormone, Seifen - Öle - Fette - Wachse. 97, (23): 876.

Schwimmer, M., Schwimmer, D. 1955: The Role of Algae and Plankton in Medicine. Grune and Stratton, New York and London.

Takagi, M. 1970: Low Molecular Nitrogen Compounds of Marine Algae. Bull. of the Fac. of Fish., Hokkaido University 21 (3): 227-233.

Tseng, C.K. and C.F. Chang 1984: Chinese Seaweeds in Herbal Medicine. Proceed. 11th Int. Seaweed Symp. 152-154.

Vinogradov, A.P. 1953: The Elementary Chemical Composition of Marine Organisms. Sears Foundation for Marine Research, Yale University, New Haven.

Wen-Young, T. 1984: Eucheuma of Taiwan - Emphasizing its Mariculture Potential. Proceed. 11th Int. Seaweed Symp. 237 ff.

Wettern, M. and A. Weber 1979: Some Remarks on Algal Carotenoids and their Interconversion into Animal Carotenoids. In: Marine Algae in Pharmaceutical Science. de Gruyter, Berlin - New York, 51-568.

Zaneveld, I.S. 1959: The Utilization of Marine Algae in Tropical South and East Africa. Economic Botany 13 (2), 89-131.